GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT INITIATION

Date: September 7, 1977

Project Title: Specialized Research Equipment: Time Domain Measurement Facility

Project No: E-21-611

Project Director: Dr. Glenn S. Smith

Sponsor: National Science Foundation

Agreement Period: From 9/1/77 Until 2/28/79
(12-month budget period plus 6-month flexibility period)

Type Agreement: Grant No. ENG77-17200

Amount: $26,700 NSF
26,638 GIT (E-21-313)
$53,338

Reports Required: Final Technical Report; Summary of Completed Project

Sponsor Contact Person (s):

Technical Matters

Division of Engineering
National Science Foundation
Washington, D. C. 20550

Contractual Matters
(thru OCA)

Ms. Mary Frances O'Connell
Grants Specialist, Area 4
Division of Grants and Contracts
National Science Foundation
Washington, D. C. 20550
(202) 632-2858

Defense Priority Rating: N/A

Assigned to: Electrical Engineering (School/Laboratory)

COPIES TO:

- Project Director
- Division Chief (EES)
- School/Laboratory Director
- Dean/Director—EES
- Accounting Office
- Procurement Office
- Security Coordinator (OCA)
- Reports Coordinator (OCA)
- Library, Technical Reports Section
- Office of Computing Services
- Director, Physical Plant
- EES Information Office
- Project File (OCA)
- Project Code (GTRI)
- Other

CA–3 (3/76)

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION

Date: May 23, 1979

Project Title: Specialized Research Equipment: Time Domain Measurement Facility

Project No: E-21-611

Project Director: Dr. Glenn Smith

Sponsor: National Science Foundation

Effective Termination Date: 2/28/79 (Grant Expiration)

Clearance of Accounting Charges: 2/28/79

Grant/Contract Closeout Actions Remaining:

_ Final Invoice and Closing Documents
X Final Fiscal ~~XXXXX~~ Accounting (FCTR)
_ Final Report of Inventions
_ Govt. Property Inventory & Related Certificate
_ Classified Material Certificate
_ Other

Assigned to: Electrical Engineering (School/Laboratory)

COPIES TO:

Project Director
Division Chief (EES)
School/Laboratory Director
Dean/Director—EES
Accounting Office
Procurement Office
√Security Coordinator (OCA)
Reports Coordinator (OCA)
Library, Technical Reports Section
Office of Computing Services
Director, Physical Plant
EES Information Office
Project File (OCA)
Project Code (GTRI)
Other

CA-4 (3/76)

E-21-611

SPECIALIZED RESEARCH EQUIPMENT:

TIME DOMAIN MEASUREMENT

FACILITY

by

G. S. Smith
School of Electrical Engineering
Georgia Institute of Technology
Atlanta, Georgia 30332

Final Technical Report
National Science Foundation Grant
ENG77-17200

May 1979

ABSTRACT

This grant provided the instrumentation for making electromagnetic measurements in the time domain. The system assembled includes a sampling oscilloscope, signal processor/controller and peripheral display devices for acquiring, storing, and analyzing repetitive electromagnetic signals with a fast rise time.

The waveforms acquired by the system can be analyzed directly in the time domain to provide information about the characteristics of the device under test or the electromagnetic phenomenon being observed. In addition, a Fourier transform can be performed on the waveforms, with the aid of the processor, to provide information in the frequency domain. Since the signals with a fast rise time have significant spectral content over several octaves of frequency, they can be used in a single measurement to characterize a device over a large bandwidth.

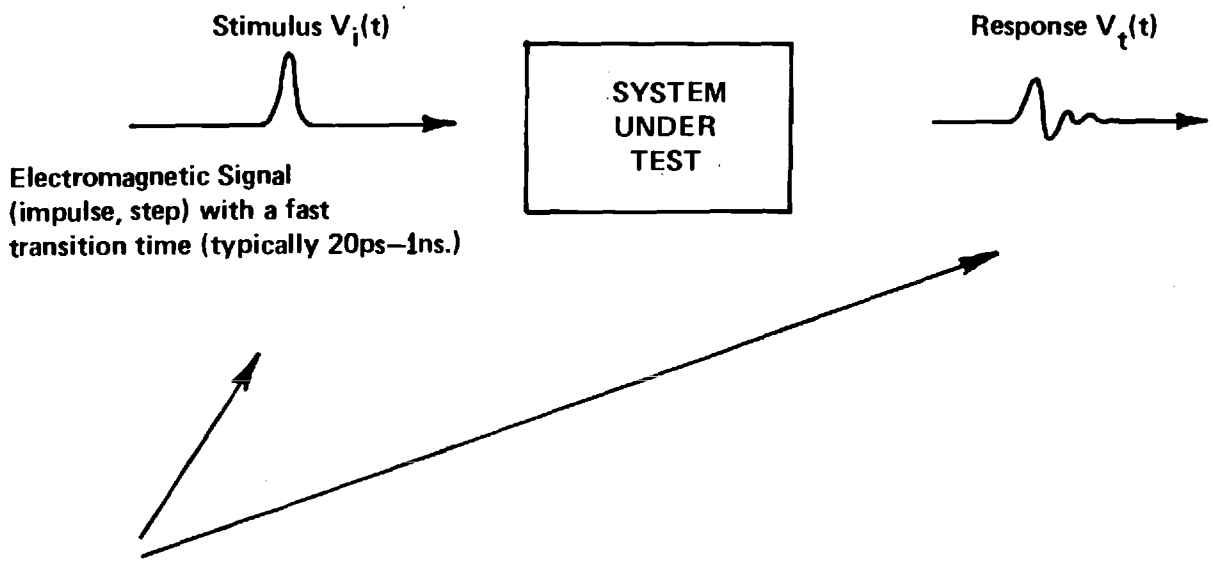
The equipment is currently being used to perform measurements in support of on-going research. These include, the measurement of the input admittance of scale model antennas over a broad band of frequencies and the measurement of the constitutive parameters of materials using monopole probes.

I. INTRODUCTION

The Research Equipment Grant from the National Science Foundation with additional funds from the Georgia Institute of Technology provided the School of Electrical Engineering with instrumentation for making electromagnetic measurements in the time domain.

Electromagnetic measurements in the time domain utilize transient signals with fast transition times, such as approximations to ideal impulses or steps, to determine the characteristics of a system. With reference to Figure 1, a stimulus $v_i(t)$ is incident on the system to be studied and a response $v_t(t)$ is measured. The transient signals $v_i(t)$ and $v_t(t)$ may be analyzed directly in the time domain to characterize the system, or, for linear systems, the Fourier transform of the signals ($v_i(t) \leftrightarrow V_i(\omega)$, etc.) may be used to obtain the characteristics of the system over a broad frequency range. For example, a system function $H(\omega) = V_t(\omega)/V_i(\omega)$ may be obtained from the transformed waveforms.

The transient signals used for this type of measurement have rise times as small as 20-30 ps ($20 - 30 \times 10^{-12}$ s). The rise time of a single waveform is too fast to be measured in real time with conventional instrumentation (oscilloscopes). To construct a facsimile of the waveform, a repetitive signal composed of several individual waveforms is used. Samples taken from each waveform in the repetitive signal are then used to construct the facsimile of the waveform (sampling oscilloscope). The sampled waveforms are processed on a computer and the desired characteristics of the system being tested are extracted by using appropriate algorithms. In a broad sense, the time-domain measurement system can be divided into two components: an electromagnetic experiment comprised of the system under test and the transient signals, and the instrumentation for processing the sampled signals.



1. Perform a direct analysis of the acquired signals in the time domain to characterize the system.

2. Fourier transform the signals to obtain the characteristics of the system over a broad frequency range.

   Ex: $V_i(t) \Leftrightarrow V_i(w)$, $V_t(t) \Leftrightarrow V_t(w)$

$$H(w) = V_t(w)/V_i(w)$$

Figure 1. Basic Approach to the Measurement

II. Description of Equipment Purchased

The elements of the time-domain measurement system are shown in a typical experimental arrangement in Figure 2. The pulse generator, transmission lines, system under test and sampler form the electromagnetic portion of the experiment. The fast rise-time pulses are confined to these elements.

After a waveform is acquired by the sampler, it is displayed on the oscilloscope and digitized and stored in the oscilloscope mainframe (digital processing oscilloscope). The digitized waveform is then passed to a controller / minicomputer where the signal processing is performed. A floppy disc is used for permanent storage of the processed waveforms or computer algorithms. Permanent records of the waveforms are made with a hard-copy unit.

A detailed list of the equipment purchased with funds from the National Science Foundation grant and additional matching funds from Georgia Institute of Technology is given in Table I.

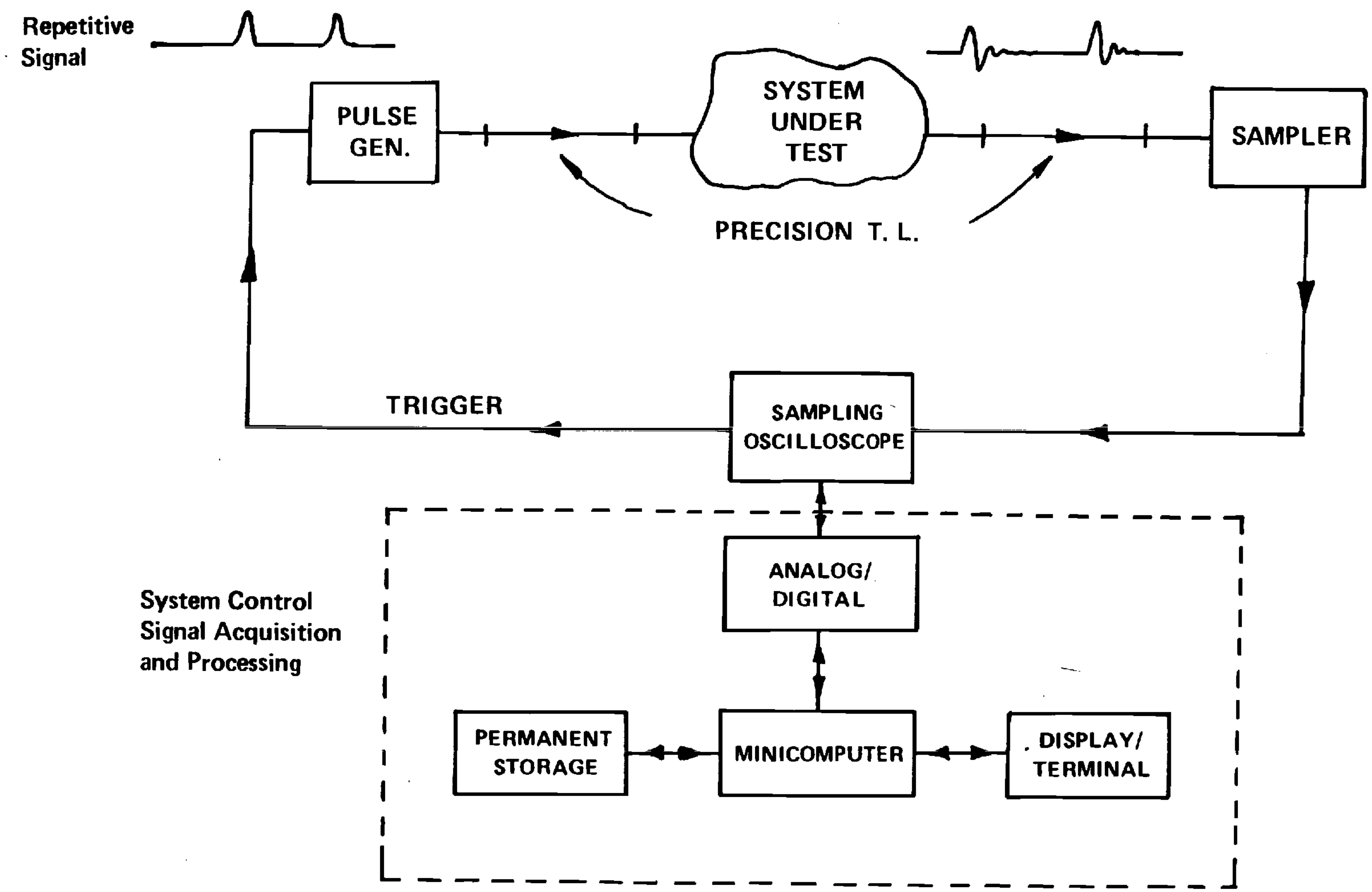


Figure 2. Elements of a Time–Domain Measurement System

Table I

List of Equipment Purchased

Signal Processing Equipment

Tektronix WP 1200 System

Including:

7704A Oscilloscope Mainframe

P7001 Processor

CP4165 Controller

CP112 Dual Floppy Disc File

SPS Basic Software

Display Equipment

Tektronix 4010-1D Display Terminal

Tektronix 4631 Hard-Copy Unit

Sampling Oscilloscope Components

Tektronix Components

7S12 Sampler

S-4 Sampling Head

S-6 Sampling Head

S-52 Pulse Generator

S-53 Trigger Recognizer

7M11 Delay Line

012-0124-00 Sampling Head Extenders (2)

Pulse Generators

IKOR Model R-100 IMP Generator

Avtech Model AVH-S Pulse Generator

Miscellaneous Electronic Equipment

Tektronix TM 500 Units (to trigger, power and monitor pulse generators)

PG501 Pulse Generator

PS503A Power Supply

TM504 Power Module

040-0303-01 Plug-in Kit

DM501 Multimeter

Coaxial Components

Hewlett Packard, Precision APC-7 Connectors and Components

Weinschel Engineering, Precision APC-7 Components

Sealectro Corp., SMA Connectors and Components

Omi Spectra, SMA Connectors and Components

Miscellaneous

Beacon Electronic Cabinet

III. Use of Equipment

The equipment assembled for the time domain measurement facility is currently being used in the following research projects.

1. Dielectric Spectroscopy Using Probes

Investigators: G. S. Smith and J. D. Nordgard

The electrical properties of linear materials can be determined over a broad range of frequencies by analyzing the Fourier transform of a transient signal that interacts with the material. A conventional approach to this measurement is to fit a sample of the material to be measured into a coaxial transmission line and monitor the transient signals made incident on and reflected from the sample.

A drawback of this method is that it requires the shape of the sample to conform to that of the coaxial sample holder. This requires the sample to be machined or cut to precise dimensions and prevents an in situ measurement. This may be a severe restriction for some materials, like biological tissue, where the cutting may destroy the sample.

A different approach to the time-domain measurement of the constitutive parameters of a linear non-magnetic material is being investigated in this research. An open structure, the short monopole, is being used to make an in situ measurement on a material with only minor modification of the sample. The signals incident on and reflected from the terminals of the probe are being analyzed to determine the scattering coefficient S_{11}, or, equivalently, the input admittance Y of the probe as a function of the frequency. The problem is then one of using an algorithm to extract the effective conductivity σ_e and permittivity ε_e of the material from the measured admittance. Symbolically,

$$\sigma_e(\omega) = S(Y(\omega))$$

$$\varepsilon_e(\omega) = E(Y(\omega)),$$

and the problem is to determine a unique expression for S and E. Theoretical analyses are now being performed to develop numerically efficient algorithms for performing this procedure.

2. Antennas in Material Media

Investigators: L. N. An (Ph.D. Student) and G. S. Smith

The electromagnetic properties of antennas in material media are being studied both theoretically and experimentally in this research program. Particular attention is being given to structures that combine a wire antenna with a dielectric insulation (insulated antennas). The terminal admittance of these antennas is being measured over a broad range of frequencies using the time domain instrumentation.

The terminal admittance of the antenna at the frequency ω is

$$Y(\omega) = Y_o \left[\frac{1 - \rho(\omega)}{1 + \rho(\omega)}\right],$$

where $\rho(\omega)$ is the reflection coefficient at the terminals and Y_o the characteristic admittance of the transmission line feeding the antenna. To determine $\rho(\omega)$, a transient signal in the form of a step with a fast rise time $v_i(t)$ is made incident on the terminals of the antenna and the reflected signal $v_r(t)$ measured. The Fourier transforms of these signals are taken using the Fast Fourier Transform Algorithm (FFT),

$v_i(t) \leftrightarrow V_i(\omega)$, etc. The reflection coefficient

$$\rho(\omega) = V_r(\omega)/V_i(\omega)$$

and terminal admittance of the antenna are then computed.

One antenna being investigated is the circular-loop antenna with an eccentric spherical dielectric insulation. Figures 3 and 4 show measured results for this antenna taken with the time-domain measurement facility. In Figure 3a, the incident step, after reflection from a short circuit is shown with the amplitude of its frequency spectrum. Note that the signal shown in Figure 3a is just the negative of the incident signal $v_i(t)$ since the reflection coefficient for the short circuit is $\rho(\omega) = -1$. The step after reflection from the terminals of the loop antenna is displayed with the amplitude of its spectrum in Figure 3b. Both signals (3a and 3b) are seen to have significant content at frequencies as high as several gigahertz.

The measured terminal admittance $Y = G + jB$ is compared with preliminary theoretical results in Figure 4. The theoretical results and those measured with the time-domain measurement facility are seen to be in good agreement. Note that the results shown are for a decade in the frequency domain and that they were measured in a matter of minutes using a single step waveform in the time domain.

A paper describing the theory for the eccentrically insulated loop antenna and these measurements is in preparation.

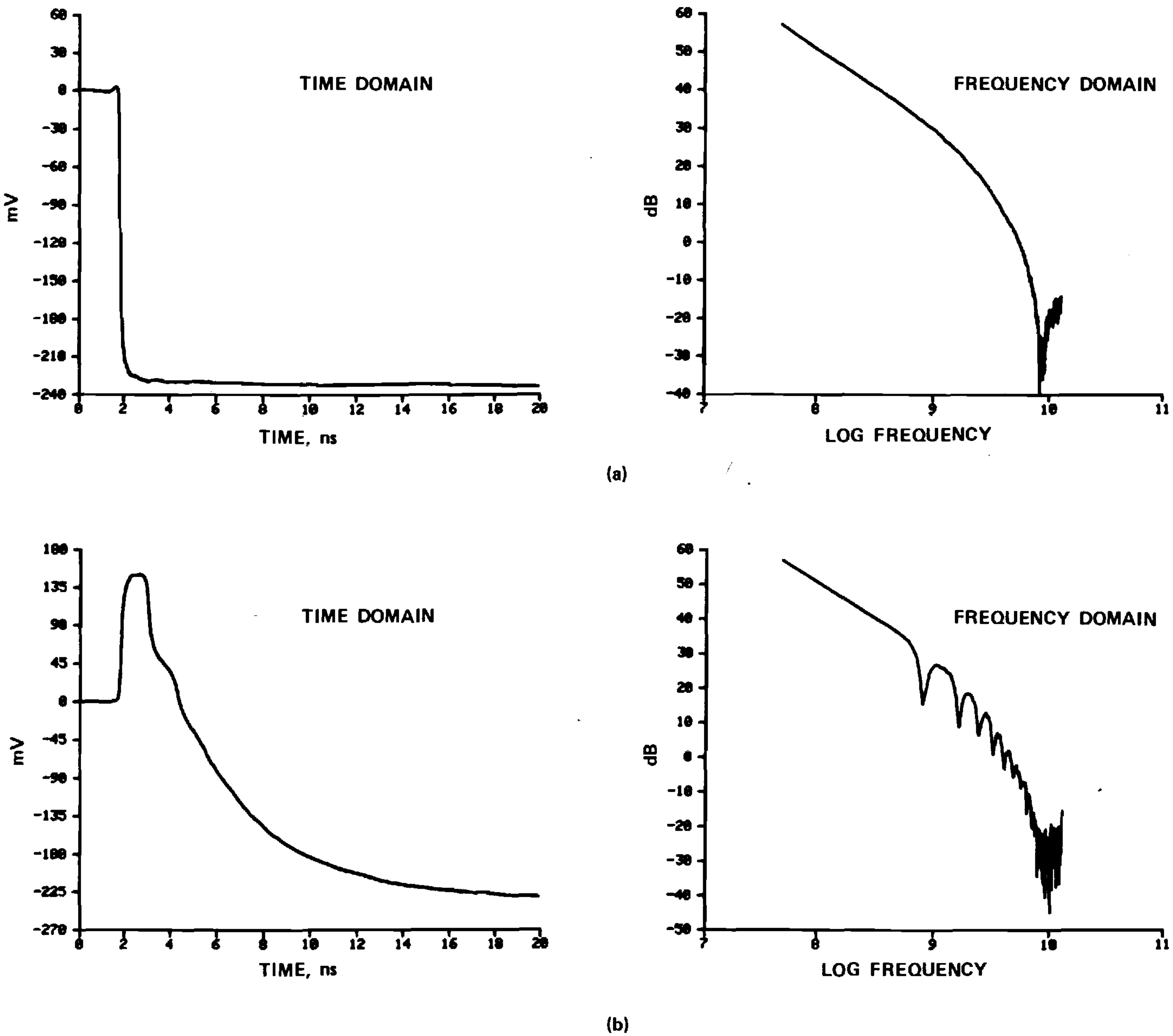


FIG. 3 a. STEP REFLECTED FROM SHORT CIRCUIT, b. STEP REFLECTED FROM LOOP ANTENNA

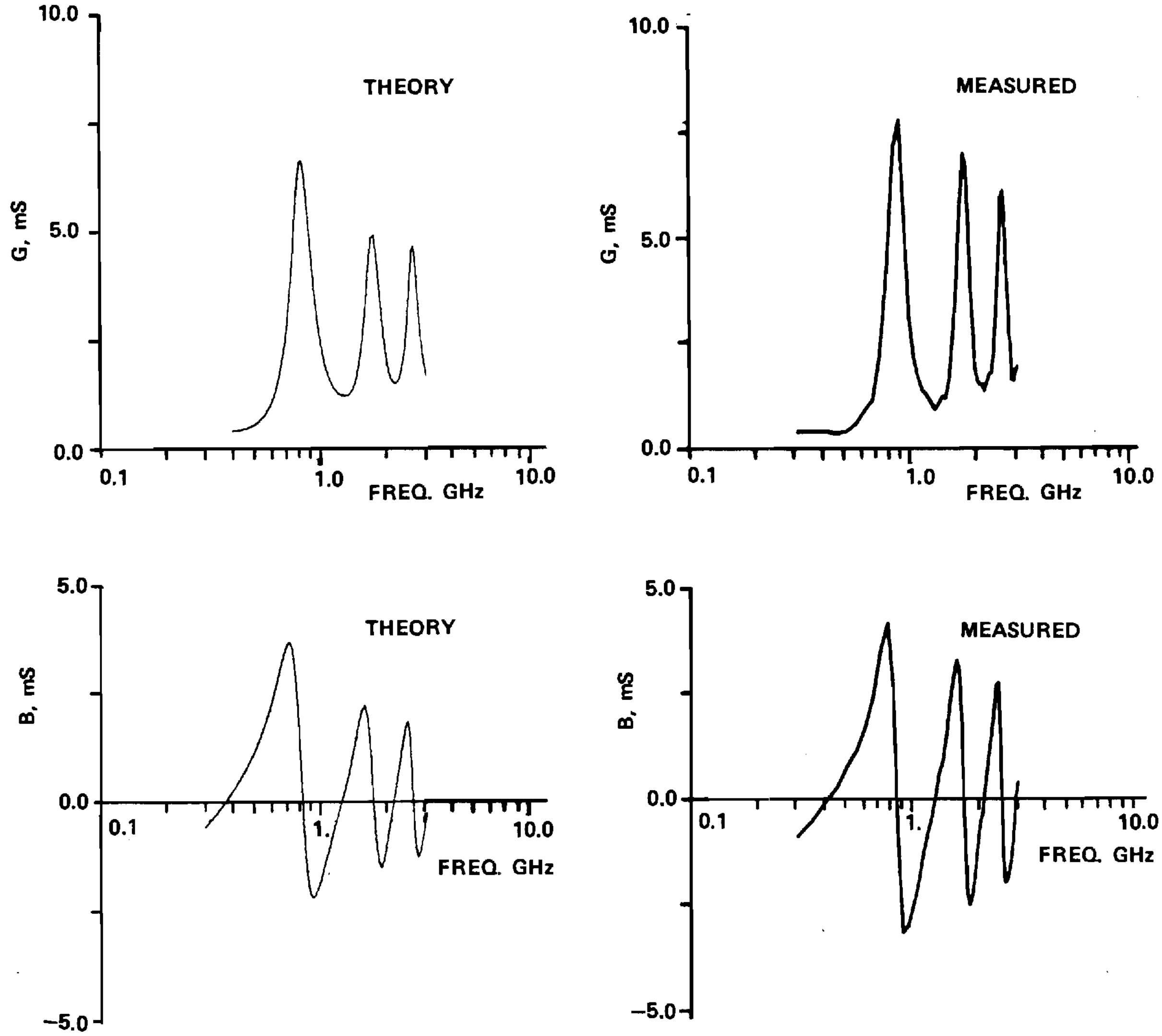


FIG. 4 COMPARISON OF THEORETICAL AND MEASURED ADMITTANCES FOR INSULATED LOOP ANTENNA.